March 16, 1937. V. Z. CARACRISTI 2,073,921

METHOD AND MEANS FOR CONTROLLING THE OPERATION OF STEAM ENGINES

Filed July 24, 1934 4 Sheets-Sheet 1

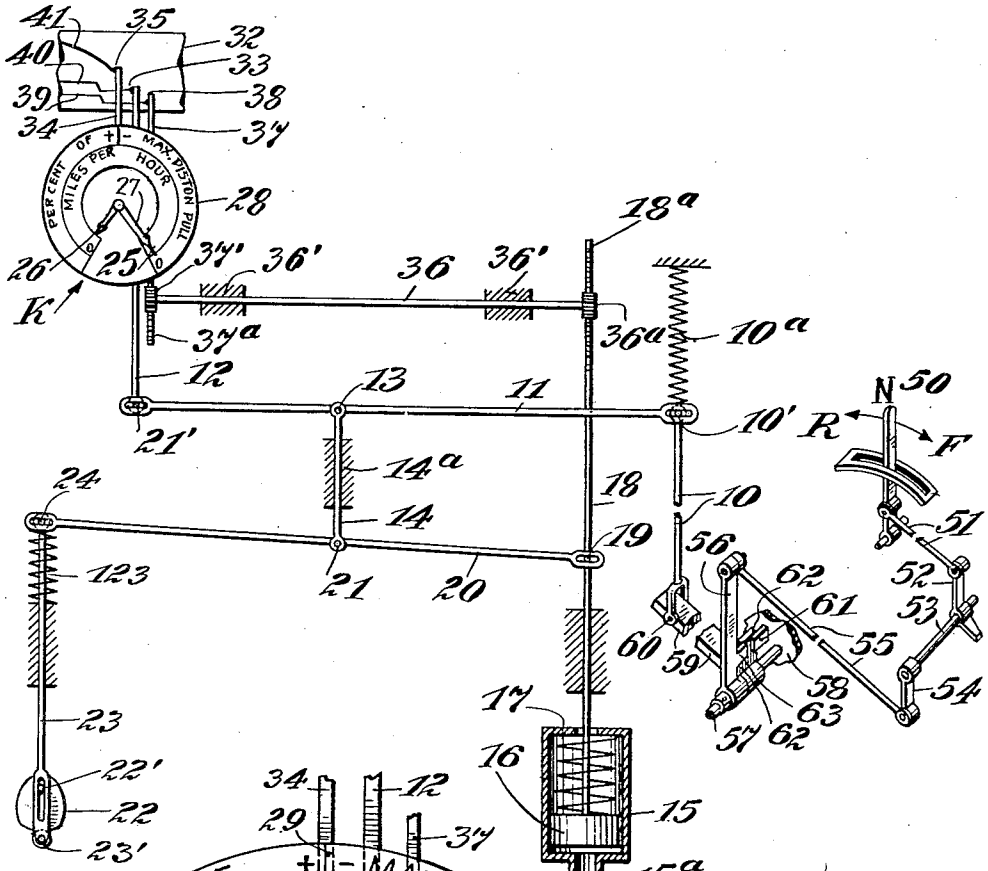


Fig. 1.

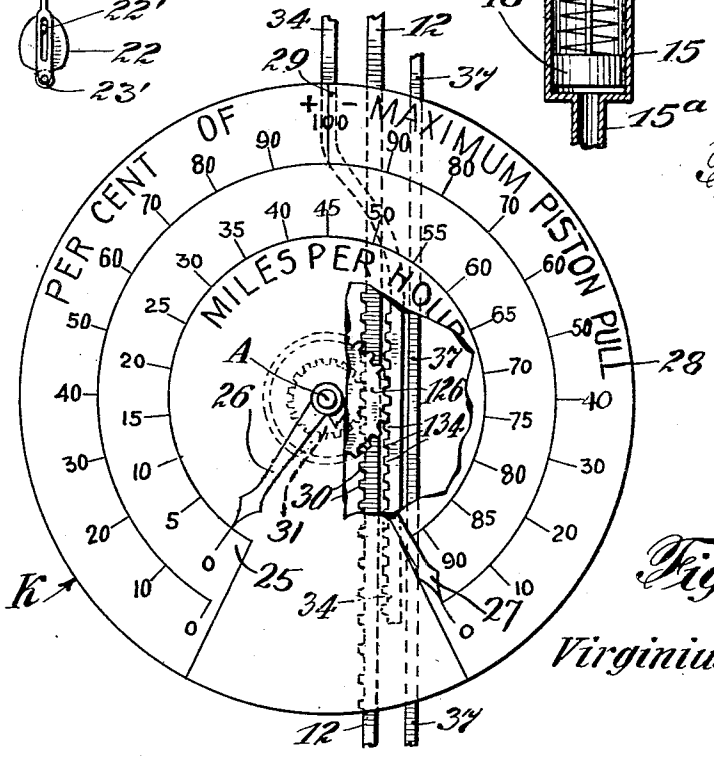


Fig. 2.

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Filed July 24, 1934 4 Sheets-Sheet 2

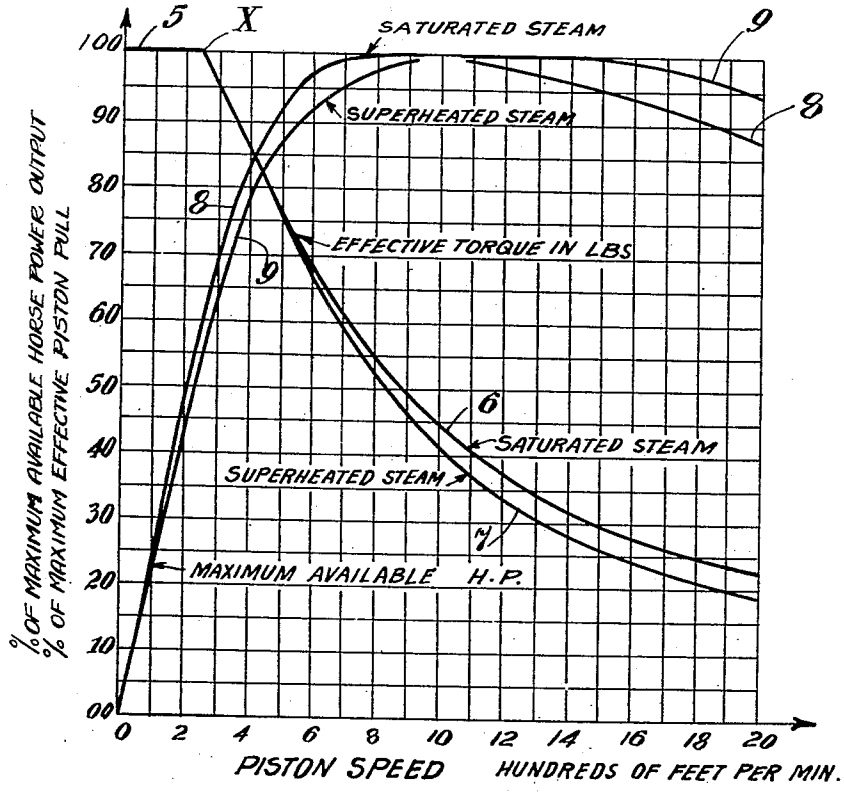


Fig. 3.

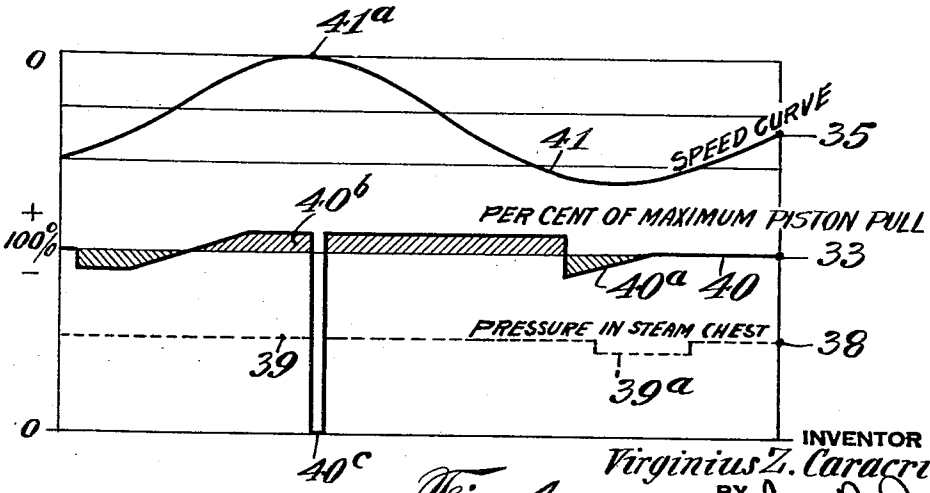


Fig. 4.

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METHOD AND MEANS FOR CONTROLLING THE OPERATION OF STEAM ENGINES

Filed July 24, 1934 4 Sheets-Sheet 3

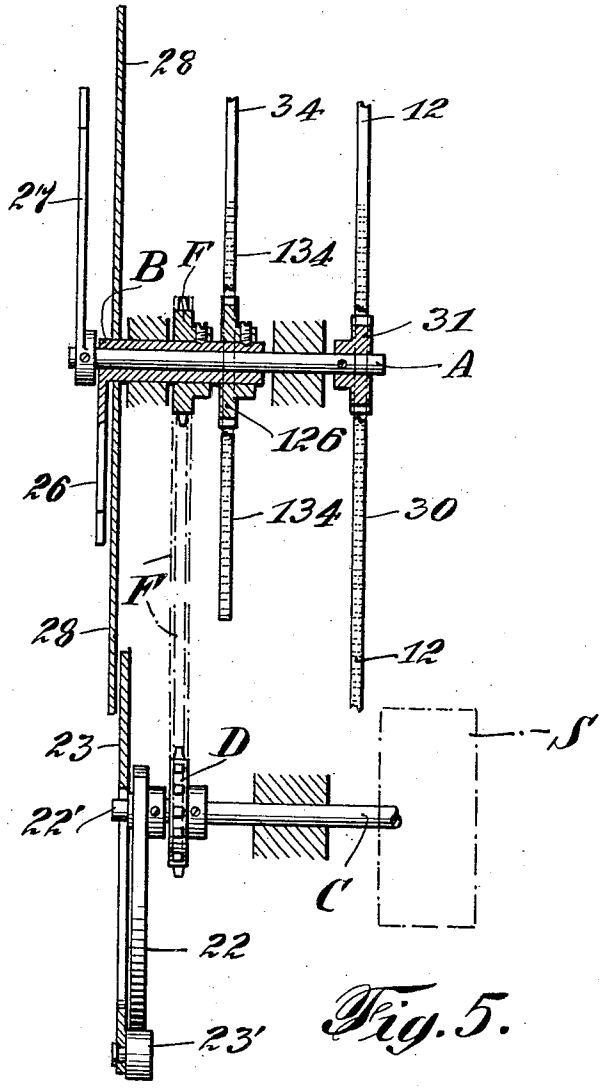


Fig. 5.

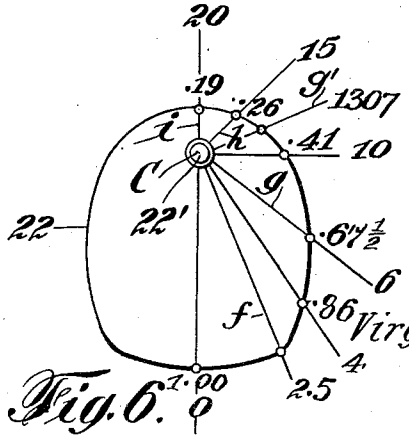


Fig. 6.

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METHOD AND MEANS FOR CONTROLLING THE OPERATION OF STEAM ENGINES

Filed July 24, 1934 4 Sheets-Sheet 4

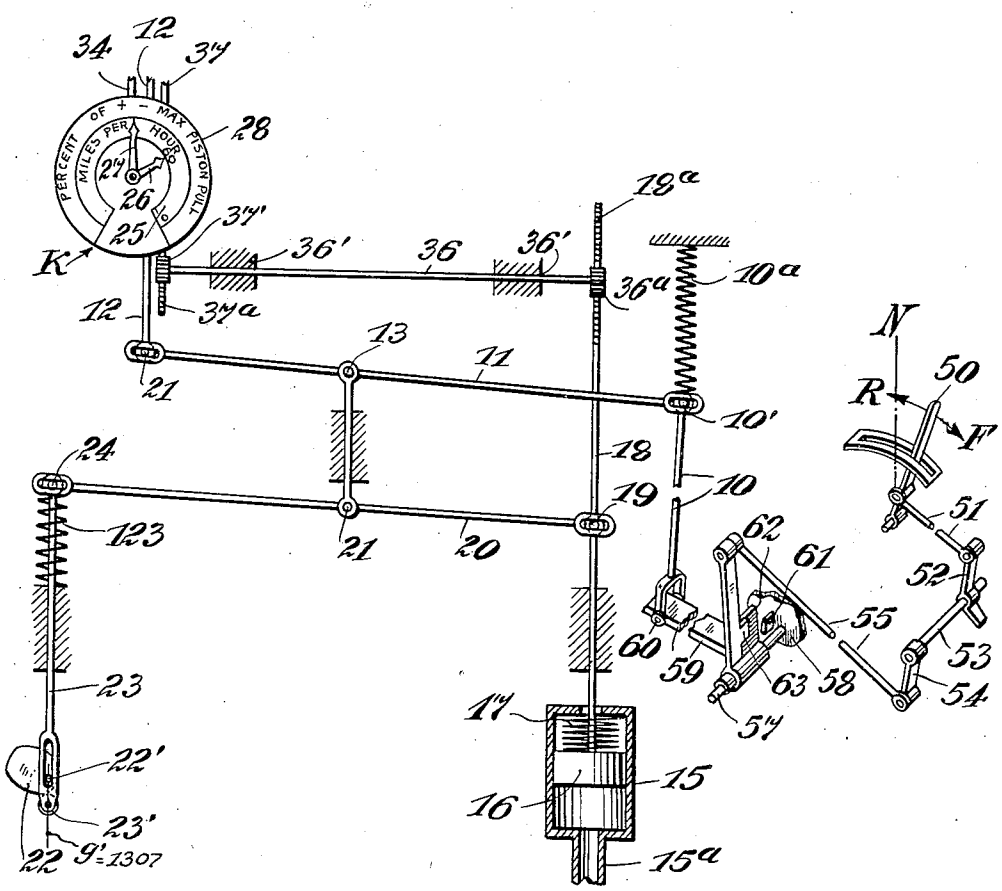


Fig. 1.

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Patented Mar. 16, 1937

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UNITED STATES PATENT OFFICE

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METHOD AND MEANS FOR CONTROLLING THE OPERATION OF STEAM ENGINES

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Application July 24, 1934, Serial No. 736,654

8 Claims. (Cl. 121—142)

The invention disclosed in this application relates generally to a method of and an apparatus for aiding an operator of a steam engine, and more particularly of a steam locomotive, to control said engine in a manner which will insure more satisfactory and efficient operation thereof by means of a single index indicating the performance in terms of percent of the maximum permissible piston pull or effort.

The present application is a continuation in part of my application Serial No. 441,476, filed April 4, 1930, for a Method and means for controlling the operation of steam engines.

It is well known to those skilled in the art of reciprocating steam engineering that there are three important and variable factors which collectively determine the degree of relative efficiency with which the engine is operating or the percentage of maximum available piston pull, which is being developed at a particular speed. These factors are piston speed, percentage of cut-off, and steam pressure. Furthermore, these factors bear a certain very definite relation with respect to each other which will be more particularly hereinafter pointed out and discussed.

It is therefore the general object and purpose of this invention to provide an apparatus for proper consideration of the variable factors of piston speed, steam pressure and percentage of cut-off, so that the individual fluctuations thereof may be suitably translated or converted into movements, and in utilizing the effect of these movements to operate suitable indicating apparatus arranged to apprise the engineer of the effective resultant of such variable factors as evidenced in the percentage of maximum available piston pull being developed or the relative degree of efficiency of operation of the engine under existing conditions of load.

It may be noted here that according to the principle of the present invention there is no correlation of any two of the variable factors, as such, but that, to the contrary, all three factors, viz, pressure, piston speed and position of the control valve, combine to produce single result or effect which is made known to the engineer by an indicating apparatus, and that in this result the factor of piston speed is not to be interpreted as or confused with surface speed. It will be appreciated that in a locomotive or other traveling engine, the surface or travel speed is dependent upon the relative size of the driving wheels and the fixed piston stroke. In my invention as herein disclosed, piston speed is the essential factor as to speed, neither the size of the driving wheels nor the resultant surface speed being a desideratum in that result. Therefore, whereas in the following specification I have referred by way of example to a speedometer as a suitable instrumentality for translating the variations in the piston speed factor, it is to be understood that such instrument is used because of its convenience for this specific purpose and that it is so used without having reference to its common and well-known function as a surface speed indicating device.

With these and other objects in view the invention comprises certain new and improved features in the method of and apparatus for generally improving and correcting existing errors in the conditions under which an engine is operating which will be fully apparent from reading the following specification when considered in connection with the accompanying drawings, wherein:—

Figure 1 is a diagrammatic view illustrating one form of my apparatus for effectively interlocking the variable factors of speed, cut-off and steam pressure, and giving each its due consideration and converting the resulting effect of such into a single force which is applied to actuate an indicating element, the several parts being shown in the relative positions they occupy when the locomotive is at rest;

Fig. 2 is an elevational view on a larger scale of the indicating apparatus, parts being broken away;

Fig. 3 is a chart showing the relation of variations in piston speeds to horse power output as expressed in percent of maximum effective piston pull and percent of maximum available horse power output;

Fig. 4 is a view of a section of the record tape having the comparative records of steam chest pressure percent of maximum horse power output, and driving speed marked thereon during a run of the locomotive;

Fig. 5 is a partial sectional view, more or less diagrammatical in character, of the indicating apparatus, showing the transmission for operating the modifying cam and the index hands, and also showing the parts for producing on the tape the lines denoting speed curve and percent of maximum piston pull;

Fig. 6 is a detailed view on a larger scale of the modifying cam; and

Fig. 7 is a view similar to Fig. 1, but without the tape, and showing the relative positions of the parts of the apparatus when the locomotive is traveling at the rate of sixty miles per hour.

Before referring specifically to the features characterizing my novel method and apparatus it is well to consider briefly the various factors which tend to complicate the problem of steam engine operation and control, particularly steam locomotives. There are various factors tending to retard or oppose the operation of an engine, or locomotive, over which the operator has little or no control. These factors include journal friction, variation in attached load, air resistance, slippage between the wheels and the rails, and others. To overcome the resultant effect of any or all of those factors which may be present in a given case, the engine operator has at his control a motive fluid in the form of steam under pressure; means for converting the energy of the steam into mechanical forces applied to impart motion to the engine, and control instrumentalities for controlling the rate at which the conversion of energy takes place. Obviously, the rate of conversion is variable within the very definite limits fixed by the boiler capacity and engine rating, and therefore the important problem from a practical standpoint is to manipulate the control instrumentalities in a manner such as to insure relatively high efficiency or economy in operation or to develop the maximum possible horse power output under prevailing conditions, as occasion demands.

The principal control instrumentality utilized in conventional locomotive control is the cut-off valve as adjusted through operation of the reverse lever. The valve is manipulated to vary the point of cut-off, that is, the period of steam admission to the engine cylinder. The amount and pressure of steam admitted to the cylinder of an engine at each stroke determines the work that the cylinder produces, and this in turn determines the available piston pull or turning effort capable of being produced. However, the amount of steam which may enter a cylinder at each stroke (for a given point of cut-off) decreases with increase in speed of operation of the engine. Bearing in mind that horse power is the rate of doing work, it is at once apparent that speed of operation has an important bearing upon the operating characteristics of an engine when considered either from a standpoint of relative efficiency or of maximum horse power that may be developed. Experience has shown that maximum turning effort or effective piston pull can be realized only through the range of piston speeds at which it is possible to maintain the mean or effective steam pressure within the cylinder at a maximum value which, for all practical purposes, is approximately 0.8 of the existing boiler pressure. Beyond this range of speeds the period of admission must be shortened to maintain steam consumption within the capacity of the boiler, and in this connection experience has also shown that if the highest efficiency is desired the cut-off valve must be operated in a manner to efficiently use the steam at the maximum rate at which the boiler can supply it.

In my apparatus, as will hereinafter appear, 100% is used to represent the maximum available horse power a locomotive is capable of constantly developing under correct position of cut-off for any speed at which the locomotive may be operating. This 100%, used as a standard, may be described as a variable constant, the variables being speed, boiler capacity, steam pressure and position of cut-off. Any combination of these variables when in correct relation to each other is expressed by the standard of 100%. Hereinafter, I show by mathematical example why it is that the relationship of locomotive travel to its piston speed is constant for any speed of the locomotive. In the description of the particular example given it is stated "This relationship of 226.195+ to 56 remains constant for any speed." Obviously this is true for all points of the cut-off, since the cut-off controls the admission of steam only and does not change the constant relationship between locomotive travel and piston speed.

With this 100% as a standard, my apparatus is devised, on the one hand, to show when and to what extent the locomotive is doing more work than the standard establishes for prevailing speed, in which event the engineer can correct the over-plus by shortening the cut-off; and on the other hand, to show when and to what extent the locomotive is doing less work than the standard establishes for prevailing speed, in which event the engineer can correct under-performance by lengthening the cut-off.

These relations between speed and horse power, and between speed and effective turning effort or piston pull are graphically shown in Fig. 3. In the chart on which these curves have been plotted the horizontal ordinates denote piston speed in hundreds of feet per minute, whereas the vertical ordinates denote percentage of maximum effective piston pull and percentage of maximum available horse power, respectively. These curves and the variations which they depict are familiar to those versed in the art pertaining to reciprocating steam engineering, and information concerning the manner in which they are plotted may be found in any recognized text-book on the subject, such as W. E. Dalby's Steam Power (see pages 439 and 448).

Referring now in particular to Fig. 3, it will be seen that I have plotted two illustrative curves indicated by the reference characters 6 and 7 and which show the effect of piston speed on available piston pull, the curve 6 showing these effects when saturated steam is used, and the other curve 7 showing the similar effects when superheated steam is used. Similarly, I have plotted two illustrative curves 8 and 9 which show the relation of piston speed to indicate horse power and of these two curves the curve 8 shows the relation when saturated steam is used, while the curve 9 shows a similar relation when superheated steam is used. All of these curves presume correct steam pressure control.

The curves 6 and 7 of Fig. 3 show that tractive force is independent of speed up to piston speeds approximating 250 feet per minute. Beyond this speed it is impossible to maintain maximum effective steam chest pressure because of the inability under higher piston speeds to maintain a maximum effective or constant value in the boiler supply, in addition as well to the effect of back pressure necessarily incident to high piston speeds. In order to maintain the mean effective pressure at or near a maximum constant value, the period of admission must be shortened at higher piston speeds, as has previously been indicated.

Curves 8 and 9 of Fig. 3 show that the maximum available horse power output increases with piston speed up to approximately 1000 feet per minute and thereafter falls off sharply. The actual value of the horse power output also increases as the point of cut-off is increased but the speed at which maximum horse power occurs

for different points of cut-off, remains substantially constant at 1000 feet per minute. Thus it is apparent that the maximum horse power output as indicated by either of the curves 8 or 9, bears a direct relationship to the possible tractive effort as influenced by piston speed, the available steam pressure and point of cut-off. Therefore, in order to insure the development of maximum horse power under existing conditions of steam pressure and piston speed, it is necessary for the engineer to correct the cut-off positions in a manner to cause the variations in effective piston pull or tractive effort to follow the curves 6 or 7, as the case may be.

It is at once apparent that, in the absence of some instrumentality which will indicate to the operator when and to what extent the actual values of these variable factors deviate from the theoretical proper values therefor, the operator must rely on his ability to properly interpret the operating characteristics of the engine to know when and to what extent to vary the cut-off. Naturally, this is a very uncertain basis of control and even in the case of enginemen with long years of operating experience, the manipulation of the throttle and cut-off is to a large extent a matter of guess-work.

With these facts in mind I have devised an apparatus for properly indicating by a single index the effect produced through the variations in steam pressure, tractive force as influenced by speed, and cut-off, by instrumentalities which, in effect, combine these several forces into a resultant, the effective variations in which are visibly indicated to the engineman in terms of percent of maximum effective piston pull being developed by the locomotive at a particular speed, so that he may know at all times what relation the actual operating conditions of the engine bear to the theoretically proper conditions.

It will, of course, be understood as this description proceeds, that insofar as the mechanical features of my present disclosure are concerned, the drawings are purely illustrative, and merely suggestive of the different functional operations whereby the modifying factors governing the proper steam chest pressure and cut-off position as affected by piston speed may be translated and converted into indicative terms comprehensible to the engineer, so that he may make the proper corrections in the position of the reverse lever as may be required for the current piston speed.

Referring now to Fig. 1 of the drawings, wherein I have illustrated one embodiment of the apparatus by which I may provide an indication of the resultant effect of the several variations hereinbefore referred to, K designates generally a composite indicating instrumentality which I will refer to more particularly hereinafter. This instrument K is operatively associated with three elements 10, 18, and 23, which are arranged to move by direct means in response to, and to reflect variations in changes in the position of cut-off, steam pressure and piston speed, respectively. The element 10 is shown as a rod suitably mounted for reciprocation in response to changes in the position of the cut-off valve of the engine. This rod is connected up with the conventional reverse lever mechanism of the locomotive on which my apparatus is to be mounted and in a manner such that, as the cut-off is moved to shorten the period of admission, the rod is raised or lifted by the tension of the pull spring 10a.

The connection between said rod 10 and the reverse mechanism of the locomotive may be accomplished in any suitable manner. For purposes of illustration I have shown the conventional reverse lever 50 connected by a link 51 with a bell crank lever 52, the latter being secured to a cross shaft 53 which in conventional locomotive practice is termed the valve or tumbling shaft, and functions through the instrumentality of said bell crank 52, to operate the usual valve gear of the locomotive engine. Also secured to the tumbling shaft 53 is an arm 54 which is connected by link 55 to a lever 56 suitably mounted for rotative or turning movement upon a shaft 57 carried by a frame member 58. Freely mounted for rotative movement upon shaft 57 is an arm 59, with which the rod 10 is pivotally connected by pin 60. In order to properly position the arm 59, I provide an abutment 61 against which a lug 62 carried by the arm 59 is normally urged by the action of spring 10a on rod 10. The lug 62 is arranged to project laterally beyond the abutment 61, as shown, and against this lateral extension of the lug 62 is engaged a lug 63 carried by the arm 56. Under this arrangement, when the reverse lever 50 is thrown forward from its central or neutral position, in which it is shown in Fig. 1, the lug 63 through its engagement with the lug 62, rocks the arm 59 in a counterclockwise direction on the shaft 57, whereupon the rod 10 is shifted downwardly. When the lever 50 is returned toward its central position, the arm 59 brings the rod 10 upwardly in a clockwise direction until the lever 50 is in neutral position, at which time the lug 62 is in engagement with the abutment 61.

The above describes the operation of this apparatus when the locomotive is moving forward. If it is in reverse motion, indicator 27 will move in the reverse direction to that described above, but the effects of variations of boiler pressure and of piston speed will be the same as above described.

The element 18 may also take the form of a rod, and is shown connected to a piston 16 arranged for reciprocation within a cylinder 15, the interior of which is in communication with the steam chest of the engine (not shown) by means of the conduit 15a. A spring member 17 is interposed between the piston 16 and one end of the cylinder so as to resist the tendency of the steam pressure acting on the under side of the piston to move the piston upwardly. Thus, as the steam pressure varies, the spring 17 will yield more or less to permit the piston 16 to move in response to such variations and these pressure variations are thereby reflected in the position of the rod 18.

It may be remarked here that by steam chest pressure, I mean the constant pressure as measured at the closest point to the cylinder where the pressure is not affected by the piston action or by the cut-off effect and is beyond the point at which frictional losses through pipes can occur. The device 15 should not be connected to the cylinder where a fluctuating pressure condition would result and thereby affect piston 16 by such fluctuating steam pressure. Steam pressure being boiler pressure less only friction losses through superheater units, etc., it follows that the device 15 should be connected to the steam chest proper where the position of the piston 16 will remain constant with boiler pressure less steam friction losses.

The element 23, also shown in the form of a rod, is arranged to reciprocate in response to changes in piston speed of the engine. To this end, I may provide an operative connection between said element and an eccentric cam member 22 mounted for actuation in response to changes in piston speed through a medium which will presently be described. As shown, the rod 23 is provided with a roller 23' which is constantly maintained in engagement with the periphery of the cam 22 by a spring 123 so that as the cam 22 shifts about its axis 22' in response to change in piston speed, the rod 23 will be shifted rectilinearly up and down, to an extent dependent upon the degree of angular movement of the cam 22. Furthermore, the cam 22 is designed so that the roller 23' in following the cam contour, will impart to the rod 23 a motion corresponding to the variations in the percent of maximum piston pull that it is possible to develop under given conditions of piston speed and cut-off, as illustrated by the curves 6 or 7 in Fig. 3. In other words, the periphery or contour of the eccentric cam is plotted so as to move the roller 23' from a position corresponding to that of the base line 5 of Fig. 3 at zero speed a distance dependent upon the speed of the piston, and which distance varies in accordance with the curves 6 or 7 of Fig. 3. Thus, any instant position of the rod 23 will indicate the percent of maximum piston pull being developed at the prevailing speed.

In view of the fact that the piston speed at which maximum piston pull is developed is practically the same for all positions of cut-off that are proper when considered in terms of the prevailing piston speed so as to use steam at the maximum rate permitted by the boiler capacity, the position of rod 23, if its movements are combined with the movements of rods 10 and 18 to move a single movable indicating element may be made to indicate by the position of the indicating element the percent of maximum piston pull being developed. For this purpose I employ certain mechanical means for translating or converting variations in the position of cut-off, pressure of steam, and piston speed as evidenced in the movements of the responsive elements 10, 18, and 23, respectively, into movement of the single indicating element or hand 27 which is movable along the face of a suitable scale 28 on instrument K, calibrated as hereinafter described in percent of maximum piston pull, to apprise the engineer of the actual and instantaneous combined effect of said responsive elements upon the output of the engine. As previously explained, the rod 10 is controlled in its movements by the movements of the reverse lever; being moved upward as the reverse lever is moved in a direction to shorten the cut-off and downward as the reverse lever is moved in a direction to lengthen the cut-off. The rod 18 is controlled in its movements by variations in steam pressure; being moved upward as steam pressure increases and downward as such pressure decreases. The rod 23 is controlled in its movements by the movements of cam 22 in response to changes in piston speed; being moved upward for increase in speed and downward as such speed diminishes. According to the operative principle of the apparatus of my invention, a downward movement is given to rod 10 when the cut-off is lengthened by moving the reverse lever from neutral, an upward movement is given to rod 18 when steam pressure increases due to the action of increasing steam pressure on piston 16, and an upward movement is given to rod 23 when piston speed increases due to the action of the eccentric cam 22 on the rod 23. Now, by each of these movements—downward movement of rod 10, upward movement of rod 18 and upward movement of rod 23—the indicating hand 27 is moved along the scale 28 in the same direction, which in the present embodiment herein illustrated is counterclockwise as will presently appear. The indicating hand 27 is moved in an opposite direction, that is to say, in a clockwise direction, when the cut-off is shortened, or when steam pressure is decreasing, or when piston speed is decreasing. If, therefore, the indicating hand 27 has been or is being moved counterclockwise by increasing steam pressure or by increasing piston speed, it may be moved in an opposite direction or clockwise by shortening the cut-off; and also, if the hand has been or is being moved clockwise by decreasing steam pressure or by decreasing piston speed, it may be moved counterclockwise by lengthening the cut-off.

The mechanism by means of which from the movements of the rod elements 10, 18, and 23 the indicating hand 27 is moved along the scale 28, comprises a system of levers arranged to integrate the movements of the individual elements 10, 18, and 23 with respect to the effect such movements (or the variations in the particular factor they reflect) has on the operation of the engine as expressed in percent of maximum piston pull being developed. Thus, considering that lengthening the cut-off has a similar effect on the operation of the engine as does raising the effective pressure within predetermined speed range and vice versa, I connect the rods 10 and 18 to my system of levers so that counter movements in said rods will cause a corresponding effect in the element 12 which is moved in response to variations in the movements of elements 10, 18, and 23 to control the operation of the single indicating element or hand 27. Likewise, as increases in speed demand decreasing the cut-off, the rod 23 is arranged to produce in the motion of the element 12 and hence in the controlled single indicating element or hand 27, which parts alike respond to variations in the resultant between elements 10 and 18, an opposite effect, that is to say, the rod 23 is arranged so that by its movements the element 12 may be given movements counter to the movements which it receives from the rod 10. With an arrangement in which the movements of element 12 derived from rods 23 and 18, are counter to the movements which are derived from the rod 10, if the system of connecting levers provides for the movement of element 12 by rod 10 a corresponding or greater movement than is obtained by the resultant movements from rods 18 and 23, then the element 12 by the rod 10 can be moved in a counter direction from the position to which it has been moved by the combined movements of rods 18 and 23. Thus, I connect the upper end of the rod 23 to one end of the lever 20 by means of a pin and slot connection 24, and to the opposite end of said lever I connect the rod 18 by a similar pin and slot connection 19. The lever 20 is pivoted intermediate its ends upon one end 21 of a link 14, said link being mounted for rectilinear reciprocation in a suitable guide 14a. The upper end of the link 14 is pivotally connected as at 13 to an intermediate part of a second lever 11. One end of this lever 11 is connected to the rod 10 by a pin and slot connection 10' so as to be moved by said rod upwardly as the cut-off is shortened, and downwardly as the cut-off is

lengthened, thus corresponding to the upward and downward movements of that end of the lever 20 which is connected to the rod 18, in response to increases and decreases, respectively, in the steam pressure. The opposite end of the lever 11 is connected by a pin and slot connection at 21' to rod 12 mounted for reciprocation, and mechanically connected by means of a rack 30 formed thereon, to a gear 31 carried by the shaft A of the single indicating element or hand 27 (see Fig. 5) of the instrument K, so as to operate the element 27 in response to variations in the position of the rod 12. In this system of levers, in which the lever 11 is rockable upon the fulcrum point 13 by the rod 10 and in which said fulcrum point is supported upon the lever 20 for raising and lowering movements accordingly as rods 18 and 23 are raised and lowered, the leverage relation is such that the rocking movement of lever 11 in any position of its fulcrum point 13, has a dominating effect in the combined leverage system whereby to move the element 12 and hence the indicating hand 27 in a counter direction a distance corresponding to any movement that can be given to said element 12 and hand 27 by the system resultant movements of rods 18 and 23. Thus it will be apparent that variations in the relative positions of the rods 10, 18, and 23, reflecting fluctuations in cut-off, steam pressure and piston pull as influenced by piston speed, respectively, are resolved by the system of levers including the elements 20, 14, 11, and 12 into movement of the hand 27 which, when associated with a suitable scale 28 calibrated in percent of maximum piston pull, will indicate to the engineer the relative percent of maximum piston pull being developed under existing conditions of piston speed, steam pressure and cut-off.

Referring more particularly to the instrument K, the same comprises a suitable speed indicating dial 25 preferably calibrated in miles per hour, and cooperating therewith is a hand or pointer 26 carried by a hollow shaft or sleeve B which in turn is mounted upon the shaft A. The hollow shaft or sleeve B is designed to be operatively connected by any suitable means with any desired speed responsive mechanism associated with the engine or locomotive, and I have illustrated in Fig. 5 mechanism suitable for this purpose.

Referring now in detail to Fig. 5, it will be seen that spindle A carries the hand 27 and also the pinion 31, while the sleeve B on said spindle A carries the hand 26. Said sleeve B may be suitably connected with a speedometer shaft C or the like for movement therewith, or with any other suitable instrument indicative of surface speed or miles-per-hour of the locomotive. The hand 26, moving in agreement with a speedometer shaft C or the like, will indicate on the dial 25 the surface speed or miles-per-hour, and its operation will be entirely independent of the operation of hand 27. The cam 22 is represented as mounted on the shaft C which carries sprocket gear D, and a transmission chain E is shown as connecting this sprocket gear D with a similar gear F on the sleeve B. By this arrangement, the integrating cam 22, as well as the hand 26, is operated from, and in agreement with, the operation of the shaft C of a speedometer S or other suitable surface speed indicating instrument. Said modifying cam 22 also constitutes one of the factors or components for operating the hand 27, as previously stated.

The instrument K is further provided with a second dial indicated at 28 in Fig. 2 which is calibrated in percent of maximum piston pull. This dial is arranged with a central calibration 29 which indicates the 100 percent point on the scale, indicating that steam chest pressure, piston speed and cut-off are all properly positioned to reproduce the maximum results corresponding to effective piston pull as shown by the curves 6 or 7 in Fig. 3. The movement of the hand 27 from such 100% position in a clockwise direction cooperates with that portion of the scale calibrated in percentages less than 100 percent and which portion is indicated by a minus sign, whereas the movement of the hand 27 in a counterclockwise direction from the such 100% position cooperates with that portion of the scale calibrated in percentages less than 100 percent and indicated by a plus sign. Thus, as will be presently explained, the position of the hand 27 on the plus side of the scale will indicate that more steam is being used than the boiler of the locomotive is capable of constantly supplying because the cut-off is too long for the prevailing speed, whereas, when the hand is on the minus side of the scale it will indicate that less than the amount of steam for the most efficient operation is being used because the cut-off is too short and that less horse power is being produced than that available within the capacity of the boiler for the prevailing speed.

In order that the maximum effective piston pull, the steam chest pressure and the speed factor may be permanently recorded during the run of the locomotive, a suitably graduated tape, a part of which is indicated at 32, may be provided on a continuously rotating drum (not shown). The part 12 has formed thereon a rack portion 30 in mesh with the pinion 31 on shaft A, and said part 12 above its rack portion is provided with a suitable marker 33 adapted to engage on one part of the tape 32. The sleeve B which carries the hand 26 may control means for operating a movable part 34 furnished with a marker 35 adapted to engage another part of the tape. The driving connection between the part 34 and the sleeve B consists of a gear 126 on said sleeve, which gear is in mesh with a rack 134 formed on the part 34.

Similarly, I may provide suitable means for indicating variations in steam chest pressure on the tape, and to this end I provide the free end of the rod 18 with a rack 18a with which is engaged a gear 36a on a shaft 36 which is mounted for rotation in suitable bearings 36'. Said shaft 36 has a second gear 37' and this is engaged with a rack 37a carried by a part 37 which is provided with a marker 38 adapted to engage another part of the tape 32. Therefore, under this arrangement, in addition to indicating the speed and percent of maximum piston by the hands 26 and 27, respectively, of the instrument K, I may provide a tape 32 on which to make a permanent record of variations in speed, steam chest pressure and percent of maximum torque.

The eccentric cam 22, which is driven in response to variations in speed of the locomotive pistons as hereinbefore described, has a combining function as shown in detail in Fig. 6. This cam is so shaped that as the piston speed increases, its point of cam contact with the roller 23' on rod 23 moves toward the axis of the cam, with the result that parts 23, 20, 14, 11, and 12 will be actuated in the direction necessary to move the hand 27 counterclockwise (as viewed in Fig. 2) from the 100 percent piston pull position. The contacting periphery of the cam is so

shaped that the maximum throw of a portion thereof, if represented by 100 percent on the base line 5 of maximum piston pull (Fig. 3), will have a constant value until through radial movement of the cam such representative portion has passed through an arc equivalent to a change in piston speed from zero to 250 feet per minute, at which point, represented on the cam by the radial line *f*, the drop-off or rescission begins to change to correspond with either of the curved lines 6 or 7 (Fig. 3) according to the character of the steam, whether saturated or superheated. When the actual movement of the cam becomes equivalent, for instance, to a piston speed of 600 feet per minute, as represented by radial line *g* on the cam, then the radial throw of the cam will become the equivalent of approximately 67½ percent of the 100 percent piston pull position, as can be noted in Fig. 3. Again, for example, when the actual movement of the cam becomes equivalent to piston speed of 1500 feet per minute, as represented by radial line *h* on the cam, its throw will be approximately 26 percent of 100 percent for line 7, or approximately 29 percent of 100 percent for line 6. When the cam movement becomes the equivalent of 2,000 feet of piston speed per minute, as represented by radial line *i* on the cam, the capacity of the engine will have been exceeded on account of the stresses ordinarily set up in the reciprocating parts thereof. It will be understood that when the locomotive is at rest or whenever the speed is zero the cam 22 occupies a position such that the point on its contour farthest removed from its center of rotation is pointed downwardly as shown in Fig. 6, with the result that the rod 23 is urged downwardly to its lowest position.

Having thus described my apparatus, I will now indicate how it functions to improve the general operating conditions of the engine. In general, and in the absence of indicating instrumentalities such as I have just described, the engineer in starting the engine usually thrusts the reverse lever to its extreme forward or rearward position (depending upon whether the locomotive is to be driven forwardly or rearwardly) and then opens the throttle to feed steam to the steam chest. As the engine speeds up the cut-off is shortened by gradually moving the reverse lever toward its neutral position and to an extent depending upon the piston speed of the locomotive and so that the engine will use steam at the maximum rate permitted by the boiler capacity. As hereinbefore stated, due to the absence of any means for properly indicating when the reverse lever is positioned to give the proper rate of steam consumption with respect to existing conditions of piston speed, ideal operating conditions are seldom, if ever, realized.

The operation of an engine equipped with my apparatus as thus described is as follows:—

As shown in Fig. 1, with the engine at rest and the throttle closed the speed hand 26 is, of course, on zero at the extreme left hand side of the scale 25, while the hand 27 is on the extreme right hand minus side of the scale due to the fact that the rod 18 is at its extreme lower position and the rod 10 is raised to its higher position. Furthermore, the position of the rod 23 in its lowest position due to zero speed, positions the hand 27 to the extreme right hand portion of the dial. To drive the engine forwardly the reverse lever is first thrust to its extreme forward position, and this causes movement of the rod 10 downwardly to its lowest point, which correspondingly moves the hand 27 in a counterclockwise position toward the 100 percent mark 29. The throttle is then opened to admit steam to the steam chest and this pressure operating upon the piston 16 moves the rod 18 upwardly and this movement is instrumental in further shifting the hand 27 in a counterclockwise direction to the 100 percent mark. The engine now begins to move and as it picks up speed beyond the point indicated by X on the curves 6 or 7 of Fig. 3, the cam 22, moving in response to such increase, shifts to allow the rod 23 to move upwardly under the tension of the spring 123, which movement is reflected by further movement of the hand 27 in a counterclockwise direction, thus carrying said hand more and more away from the 100 percent mark 29 on the plus side of the scale. This indicates to the engineer that the prevailing position of the cut-off is too long for the prevailing speed, and, accordingly, the cut-off is shortened by moving the reverse lever towards its neutral position, which operation is reflected by an upward movement of the rod 10 and a clockwise movement of the hand 27. Thus, the reverse lever is operated in response to changes in the speed to maintain the hand 27 as nearly as possible on the 100 percent mark 29 at all times in order that the engine will give the percent of maximum available piston pull. If it is desired to operate under conditions of maximum efficiency with regard to steam consumption, the cut-off is manipulated to maintain the hand 27 over as far as possible on the minus side of the scale, and this condition of maximum efficiency can be accomplished only by operating under shortest possible cut-off. Fluctuations in steam pressure will, of course, be reflected directly in speed variations so that variations in either or both of these factors will be evidenced by movement of hand 27 clockwise for falling speed, for falling steam pressure, or both and counterclockwise by rising speed, by rising steam pressure, or both. Thus the instrument K keeps the engineer constantly apprised by the position of hand 27 on the scale 28, giving thereby a visual indication of existing operating conditions, with reference to prevailing speed, steam pressure, and cut-off, by which the engineer may effectively adjust the reverse lever to properly set the cut-off valve to distribute the steam at the most economical effective rate. In this way the maximum available effort of the engine at a particular speed, without causing a drain on the boiler, can be realized. At the same time the engineer may be apprised of the locomotive speed by referring to hand 26.

In contrast to Fig. 1 where I illustrate the rods 10, 18, and 23 and the hands 26 and 27, in the relative positions which they may assume when the engine is at rest, Fig. 7 shows the same parts in the relative positions which they may respectively assume when the engine is moving approximately at the rate of sixty miles per hour under correct steam pressure control. In Fig. 7, it will be seen that the reverse lever 50 has been moved to an intermediate position towards neutral from its full forward throw of 100 per cent open position, and this of course means that the cut-off has been shortened under the demands of increased piston speed. The piston 16 is shown elevated in response to the steam pressure in the steam chest, and the modifying cam 22 is represented as having been turned to a position in which its periphery is in contact on the line *c—g'* with the roller 23'.

The cam contact with the roller at or about the

line c—g' denotes a piston speed of about 1307 feet per minute, and this piston speed, when translated into terms of miles-per-hour, means that the locomotive is traveling approximately at the rate of 60 miles per hour, as will presently appear. In Fig. 7, the hand **26** is pointing to the 60 miles-per-hour notation on the dial **25**, indicating thereby the locomotive speed, while the hand **27** is pointing to the maximum 100 per cent piston pull notation on dial **28**, indicating thereby that the cut-off is in proper position for the prevailing 60 miles-per-hour speed.

Speed effect is usually graduated in miles-per-hour, the speed formula at the rate of 60 miles per hour being, per minute mile,

$$88\left(\frac{5280}{60}\right)$$

feet, or its equivalent 1056 (88×12) inches. It is of course well known that piston speed is twice the piston stroke multiplied by the complete number of cycles per minute. Assuming that the locomotive is one having 72-inch (diameter) driving wheels and having a 28-inch piston stroke, such locomotive will travel 226.195+(3.1416×72) inches when the piston travels 56 (2×28) inches. This relationship of 226.195+ to 56 remains constant for any speed. Now there are 63,360 (5280 ×12) inches in a mile. The circumference of the driving wheel being 226.195+ inches and the number of revolutions per mile being

$$280.11+\left(\frac{63360}{226.195+}\right)$$

each revolution of the drivers under 56-inch piston travel is

$$1307\left(\frac{56\times 280.11+}{12}\right)$$

feet, which is the piston speed of the engine when traveling at the rate of 60 miles per hour.

Referring now to Figs. 5, 6, and 7, the cam **22** will be turned by the speed mechanism to a point corresponding with this piston speed as illustrated by the line c—g' which is equivalent, as shown by the hand **26** on the dial **25**, to 60 miles per hour. From the foregoing it will be obvious that each change in the relationship between piston stroke and driving wheel diameter will necessitate a new determination of the cam stroke and angles in order that speed in miles per hour will be converted into piston speed in feet per minute. As hereinbefore explained, it is to be understood that the use of the hand **26** and its accompanying dial **25** is entirely immaterial to the use and operation of this invention, said hand and dial being shown herein only for the purpose of demonstrating more fully how the cam functioning as the speed element, is one of the three variable factors, namely, pressure, piston speed and position of the control valve. As previously pointed out the actions of these three variables are consolidated into a single result or effect which is made known to the engineer by the movement of the hand **27** over the dial **28**.

When the hand **27** moves over the plus side of the dial from the 100 per cent point, such movement is a certain indication that the cut-off is too long for the prevailing speed and hence that steam is being wasted. When this hand moves over the minus side of the dial from the 100 per cent point, such movement is a certain indication that the cut-off is too short for the prevailing speed and that more steam may be used without waste. The hand **27** always moves clockwise or to the right for falling steam pressure, for falling speed, or both, indicating that the cut-off should be lengthened; and said hand always moves counterclockwise or to the left for rising steam pressure, for rising speed, or both, indicating that the cut-off should be shortened. The control calibration **29** represents the 100 per cent efficiency position for the hand **27**; that is to say, the maximum piston pull at boiler capacity without waste at a prevailing speed.

Referring to Fig. 4, wherein I have illustrated a set of typical curves or graphic records of engine operation as inscribed on the tape **32** by the markers **33**, **35**, and **38**, curve **41** shows possible variations in speed; curve **40** shows the variations in 100 percent of maximum available piston pull being developed, and curve **39** shows variations in the pressure. The various events, as depicted in these several curves, are also shown, as for instance, the part **41a** on curve **41** will represent that zero speed is supplied in curve **40** by the zero point **40c**. Likewise, the point **40a** in curve **40** indicates that the cut-off was shunted to move hand **27** from one side of the scale to the reverse side thereof, and this is evidenced by the preceding and successive portions of this curve, occupying a position off base and below the 100 percent line **33**. The drop in steam pressure is responsible for the drop **39a** in curve **39**. With regard to Fig. 4 it is desired to state that the driving speed marked on the record is independent of other markings, and that as to the individual mechanism for producing the driving speed marking I claim no invention, this particular marking and the mechanism for producing the same being shown and described only for the purpose of pointing out a further use of the apparatus that may be conveniently made at a slight extra cost.

This invention does not in any way apply to devices pertaining to cylinder performance and cannot be used to obtain data necessary for the study of steam expansion or efficiency.

In conclusion, therefore, it is apparent that by the method and apparatus herein described, I convert variations in position in cut-off, steam pressure and tractive force as influenced by piston speed, into forces which I combine and resolve into a single resultant force which is applied to actuate an indicating element in response to variations in said resultant force, whereby to constantly apprise the engineer of conditions under which the engine is operating, so that he may, by adjustment of the cut-off in accordance with said indication, insure proper and efficient operation of the engine at all times.

I claim:—

1. In combination, an engine indicator including a movable indicating element, means for indicatively moving said element and means for actuating said element moving means including a lever pivoted intermediate its ends, said lever at one end being connected to said actuating means and at its other end being provided with means for connection to the valve control for the propulsion medium of the engine, means movable in response to variations in pressure of steam supplied to the engine, and means movable in response to variations in engine driving piston pull as influenced by piston speed thereof, said actuating means also including an operative connection between the element moving means and said means movable in response to variations in steam pressure, and an operating connection between the element moving means and the means movable in response to variations in engine driving piston pull, whereby the

relative positions of the indicating element and cut-off adjusting mechanism may be modified to compensate for variations in steam pressure and driving piston pull.

2. In combination, an engine indicator including a movable indicating element, means for indicatively moving said element and means for actuating said element moving means including means for operatively connecting the moving means to the valve cut-off adjusting mechanism of the engine for movement thereby, means movable in response to variations in pressure of steam supplied to the engine, and means movable in response to variations in engine driving piston pull as influenced by piston speed, a lever pivoted intermediate its ends, one end of said lever being operatively connected to the means movable in response to pressure variations, the opposite end of said lever being connected to the means movable in response to variations in engine driving piston pull, and means for transmitting movements of said lever to said actuating means for the indicating element whereby the variations in the position of cut-off, in steam pressure, and driving piston pull as influenced by piston speed are combined to give a single indication.

3. In combination, an engine indicator including a movable indicating element, means for indicatively moving said element and means for actuating said element moving means including a lever pivoted intermediate its ends, said lever at one end being connected to said actuating means and at its other end being provided with means for connection to the valve control for the propulsion medium of the engine, means movable in response to variations in pressure of steam supplied to the engine, and means movable in response to variations in engine driving piston pull as influenced by piston speed thereof, a lever pivoted intermediate its ends, one end of said lever being operatively connected to the means movable in response to pressure variations, the opposite end of said lever being connected to the means movable in response to variations in engine driving piston pull, and means for transmitting movement of the second mentioned lever to the first-mentioned lever, whereby the variations in the position of cut-off in steam pressure, and in driving piston pull as influenced by piston speed are combined to give a single indication.

4. In combination, an engine indicator including a movable indicating element, means for indicatively moving said element and means for actuating said element moving means including a lever pivoted intermediate its ends, said lever at one end being connected to said actuating means and at its other end being provided with means for connection to the valve control for the propulsion medium of the engine, means movable in response to variations in pressure of steam supplied to the engine, and means movable in response to variations in engine driving piston pull as influenced by piston speed thereof, a lever pivoted intermediate its ends, one end of said lever being operatively connected to the means movable in response to pressure variations, the opposite end of said lever being connected to the means movable in response to variations in engine driving piston pull, and means for transmitting movement of the second-mentioned lever to the first-mentioned lever including a link connecting the pivot points of said levers whereby to move the same in unison in accordance with the relative movement of said levers, whereby the variations in the position of cut-off, in steam pressure, and in driving piston pull as influenced by piston speed are combined to give a single indication.

5. In combination, an engine indicator including a movable indicating element, means for indicatively moving said element and means for actuating said element moving means including means for operatively connecting the moving means to the valve cut-off adjusting mechanism of the engine for movement thereby, means movable in response to variations in pressure of steam supplied to the engine, and means movable in response to variations in engine driving piston pull as influenced by piston speed of operation thereof, said actuating means also including an operative connection between the element moving means and said means movable in response to variations in steam pressure, and an operating connection between the element moving means and the means movable in response to variations in engine driving whereby the position of the indicating element is modified by the valve cut-off adjusting mechanism to compensate for variations in the driving piston pull and in steam pressure.

6. The method of indicating locomotive operation comprising converting variations in position of cut-off, in steam pressure and in tractive force as influenced by piston speed into forces varying, respectively, in magnitude and direction in accordance with the effect such variations have toward increasing or decreasing the horse power output of the locomotive; combining said forces into a single force varying in magnitude and direction in accordance with the resultant effect of all of said variations upon the horse power output of the locomotive, and indicating variations in the horse power output of the locomotive in response to variations in magnitude and direction of said resultant force.

7. The method of indicating locomotive operation comprising reproducing variations in position of cut-off, in steam pressure, and in tractive force as influenced by piston speed, respectively, by movement of control media from one position to another; combining both as to direction and magnitude the relative movements of said media in accordance with the effect said respective variations have toward increasing or decreasing the horse power output of the locomotive; reproducing variations in the cumulative effect of said variations as thus integrated by movement of a single control element in accordance with the resultant effect said variations have toward increasing and decreasing horse power output of the locomotive; and indicating variations in the horse power output of the locomotive due to the resultant effect of said individual variations in response to variations in position of said single control element.

8. Resultant means for indicating the performance of a steam engine in terms of percent of maximum available piston pull, the engine comprising a propulsion medium valve control means, steam pressure responsive means and driving piston pull responsive means responsive to the piston speed of the engine, a movable indicating element and its percentage calibrated maximum available piston pull dial, connections connecting the indicating element with the valve control means and the steam pressure responsive means whereby variations in the operation of each of said means are resultant into and effect

the movement of said element in either direction with respect to its calibrated dial, and a connection interconnecting the driving piston pull responsive means with the first-named connections to combine variations in the operation of the driving piston pull responsive means into the operation of said connections, said driving piston pull responsive means and the interconnections therewith being active on and through the first named connections to effect the movement of said indicating element reversely in either direction with respect to the movements thereof caused by either the valve control means or by the steam pressure responsive means.

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